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HEAT TRANSFER AUGMENTATION IN A PLATE-FIN HEAT EXCHANGER: A REVIEW

Shankar Lal and Chhagan Lal Kharol
M. Tech Scholar, Aravali Institute of Technical Studies, Udaipur, Rajasthan, India

Chetan Jaiswal
Associate Professor, Aravali Institute of Technical Studies, Udaipur, Rajasthan, India

ABSTRACT

The improvement of the performance of heat exchangers with gas as the working fluid becomes particularly important due to the high thermal resistance offered by gases in general. In order to compensate for the poor heat transfer properties of gases, the surface area density of plate heat exchangers can be increased by making use of the secondary fins such as, off-set fins, triangular fins, wavy fins, louvered fins etc. In addition, a promising technique for the enhancement of heat transfer is the use of longitudinal vortex generators. The longitudinal vortices are produced due to the pressure difference generated between the front and back surface of the vortex generator. The longitudinal vortices facilitate the exchange of fluid near the walls with the fluid in the core and hence, the boundary layer is disturbed. It causes the increase in temperature gradient at the surface, which leads to the augmentation in heat transfer. An innovative design of triangular shaped secondary fins with rectangular or a delta wing vortex generator mounted on their slant surfaces for enhancing the heat transfer rate in plate-fin heat exchanger is proposed.

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1. INTRODUCTION

1.1. Heat Exchangers

A heat exchanger is a device, which is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a

fluid, at different temperatures and in thermal contact. Not only are heat exchangers often used in the process, power, petroleum, air-conditioning, refrigeration, cryogenic, heat recovery, alternative fuel, and manufacturing industries, they also serve as key components of many industrial products available in the market. The heat exchangers can be classified in several ways such as, according to the transfer process, number of fluids and heat transfer mechanism. Conventional heat exchangers are classified on the basis of construction type and flow arrangement. The other criteria used for the classification of heat exchangers are the type of process functions and fluids involved (gas-gas, gas-liquid, liquid-liquid, two phase gas etc.). The classification according to the surface compactness deals with one of the important class of heat exchangers named as compact heat exchangers.

1.2. Extended surface heat exchangers

Heat exchangers, based on constructional details, can be classified into tubular, plate-type, extended surface and regenerative type heat exchangers. The tubular and plate–type exchangers are the primarily used surface heat exchangers with effectiveness below 60% in most of the cases. The surface area density of these heat exchangers is usually less than 700 m^2/m^3. In this regard, an important fact is that the thermal conductance 'h.A' on both sides of the heat exchanger should approximately be the same. Hence, the heat transfer surface on the gas side needs to have a much larger surface area as it is well known that the heat transfer coefficient 'h' for gases is much lower than that for liquids. One of the most common methods to increase the surface area and compactness is to have extended surface (fins) with an appropriate fin density (fin frequency, fins/m) as per the requirement. This addition of fins can increase the surface area by 5 to 12 times the primary surface area. These types of exchangers are termed as extended surface heat exchangers. The heat transfer coefficient 'h' on extended surfaces may be higher or lower than that of un-finned surfaces. The louvered fins increase both the surface area and the heat transfer coefficient, while the internal fins in a tube increase the tube surface area but may result in a slight reduction in heat transfer coefficient depending on the fin spacing. However, the overall thermal conductance increases due to the presence of extended surfaces.

2. LITERATURE REVIEW

A considerable amount of experimental as well as analytical and computational research has been carried out on the enhancement of heat transfer. In this chapter, a brief survey of the relevant literature is presented to indicate the extent of work already reported in open literature pertaining to the enhancement of heat transfer by introducing protrusions mounted on the heat transfer surfaces.

Grosse-Gorgemann et al. [1993] showed that the enhancement mechanism by transverse vortex generators need unsteady flow and develop reversed flow regimes which further increase the resistance to flow. No enhancement in heat transfer was reported for steady flow in a periodically ribbed channel.

Ghaddar et al. [1986] and **Amon and Mikic [1990]** investigated numerically the grooved channel flow where the grooves were so short that the separated flow was attached at the face of the next protrusion instead of the base of the groove.

Turk et al. [1986] investigated heat transfer enhancement for laminar flow over a row of rectangular winglet pairs by varying the aspect ratio. The angle of attack was fixed at 20°. It was found that the ratio of span averaged heat transfer coefficient on a

flat plate with vortex generator to the corresponding value without vortex generator increased up to 3 at a distance more than 30 chord lengths downstream of the winglets. The study was carried out both for zero and favorable pressure gradients and heat transfer enhancement was found to be more with favorable pressure gradient.

Torii et al. [1991] investigated local heat transfer downstream of a single delta winglet vortex generator on a flat plate. Flow visualization experiments were conducted to study the flow field and hot wire anemometer was used to measure the velocities. Naphthalene sublimation and surface thermocouples with an imposed heat flux were used to measure the heat transfer. The free stream velocity was fixed to 4 m/s. Local heat transfer enhancement of over 200% was reported in the downwash region of the flow. The velocity data provided the information about the vortex location.

Gentry and Jacobi [1997] studied the effect of streamwise vortices induced by delta wing vortex generator. Flow visualization techniques were used to study the flow and naphthalene sublimation was used to get the heat transfer effects. It was concluded that the maximum heat transfer enhancement is observed when a vortex is located near the edge of the thermal boundary layer. Further it was reported that the vortices should be generated in a common inflow arrangement so that the induced velocities keep the vortices near the boundary layer.

Eibeck and Eaton [1987] studied a single vortex using a Rankine vortex model for the turbulent flow and velocity data. They interpreted their data in terms of vortex circulation and boundary layer thickness. The experiments were conducted using a constant heat flux surface. The local increase in the Stanton number was attributed to a thinning of the boundary layer on the downwash side of the vortex.

Pauley and Eaton [1988] extended this work for the vortex pairs. Co-rotating pairs moved together and coalesced into a single vortex while being advected downstream. This research provided useful insights about the vortex-vortex and surface-vortex interactions.

Biswas et al. [1994(a)] numerically investigated the flow structure and heat transfer enhancement in a staggered row circular tube-fin channel with delta winglet vortex generators mounted on the fin surfaces. Steady solutions were obtained up to a Reynolds number of 500. At the channel inlet, a fully developed velocity profile for the axial velocity was assumed. The winglet vortex generator placed in the wake region of the circular tube enhances the heat transfer by as high as 240 % along with the increased overall channel heat transfer.

Torii et al. [2002] numerically evaluated the delta winglet pair in common flow-up configuration at low Reynolds number to meet the various demands of the designers such as compactness, fan power saving and quietness etc. This configuration accelerates the fluid flow and as a consequence, the delay in separation occurs and form drag is also reduced due to narrowing of the wake and suppression of the vortex shedding. The zone of the poor heat transfer is also removed, since the fluid is accelerated in this passage. In an in-line tube arrangement, the common flow-up configuration augmented the heat transfer by 10 to 20 % and simultaneously decreased the pressure drop by 8% to 15%. A much better performance was observed in a staggered tube arrangement with the same common flow-up configuration. The in-line and staggered tube configurations are shown in Figure 2.4. For a Reynolds number of 350, a pressure loss reduction of 55 % was achieved together with a heat transfer enhancement of 30%.

Torii et al. [2002] also studied the in-line tube banks with delta winglets in common flow-down configuration as proposed by Fiebig et al. [1993]. The vortex generators enhanced the heat transfer by 10 % to 25 % with 25 % to 35 % increase in pressure penalty. Further, this configuration is not so effective for low Reynolds numbers. The corresponding increase in heat transfer was also less for the staggered tube arrangement.

Kwak et al. [2003] experimentally evaluated two to five rows of staggered circular tube bundles with a single transverse row of delta winglets in common flow-up configuration placed beside the front row of tubes. For three row tube bundles, the heat transfer was augmented by 10 % to 30 % and yet the pressure loss was reduced by 34% to 55% with an increase in Reynolds number from 350 to 2100.

Pesteei et al. [2005] performed the experiments to study the effect of the winglet location on the heat transfer enhancement and pressure drop in a fin-tube heat exchanger. Height of the delta winglet was the same as of the channel and the aspect ratio and the Reynolds number was fixed at 1.33 and 2250 respectively. The winglet was mounted at an angle of attack of 45o, which is the best angle for the fin-tube arrangement as reported by **Fiebig et al. [1990].** The study showed that for the highest local heat transfer coefficient, the winglet pair should be placed at a distance of half of the tube diameter both in X and Y directions. The winglet pairs were found to be most effective when placed on the downstream side. Mounting the delta winglet pair on the upstream side did not produced any significant effect on the heat transfer coefficient and it was argued that at this location, winglet pair produces very strong horse-shoe vortices because of the presence of the tube.

Tiwari et al. [2003] studied numerically the various combinations of the delta winglet pairs in a rectangular channel with a built in oval tube. A finite volume method due to Eswaran and Prakash [1998] was used to discretize and solve the governing equations. The spanwise average Nusselt number for the case of four winglet pairs was found to be about 100% higher as compared to the no winglet case at a Reynolds number of 1000. Some different combinations of the pair of delta winglet vortex generators were also analyzed by **Prabhkar et al. [2003]** in a rectangular channel with built-in oval tube. **Tiwrai et al. [2005]** studied numerically the effect of wake splitter placed behind the circular tubes in a cross flow configuration.

Chen et al. [1998] predicted the influence of the angle of attack and the aspect ratio of a punched delta winglet pair placed near the leading edge of the finned oval tube. Here the non-isothermal boundary condition of the fin was considered due to conjugate heat transfer in the finned tube. The computational domain was discretized into a finite number of control volumes and the winglet was approximated by the interface between two control volumes. A slight change in the location of the winglet pair produced little change in the heat transfer rate.

Fiebig et al. [1993] experimentally evaluated the effect of delta winglets in a tube-fin heat exchanger. For the in-line tube arrangement, the winglets caused a 55-65% increase in heat transfer with a 20-45% increase in friction factor within the Reynolds number range 600-270.

Fiebig et al. [1994(b)] performed the experiments to compare the round and flat tubes with longitudinal vortex generators. For the staggered fin and tube arrangement, the heat transfer was increased by 10% for round tubes as against a much more significant 100% for flat tubes. The loss in pressure was also half of that for round tubes.

3. CONCLUSION

Literature survey shows the potential of longitudinal vortex generators to augment heat transfer in various types of geometries. However, only little work is done with a combination of longitudinal vortex generators and secondary fins as inserts between the parallel plates of a plate-fin heat exchanger. The present study is carried out on triangular shaped secondary fins, with delta/rectangular wings on their slant faces, sandwiched between the parallel plates of plate-fin heat exchanger.

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